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F1V VCAA V106 V111 V416 V420
H1R RBK

(56) Documents Cited

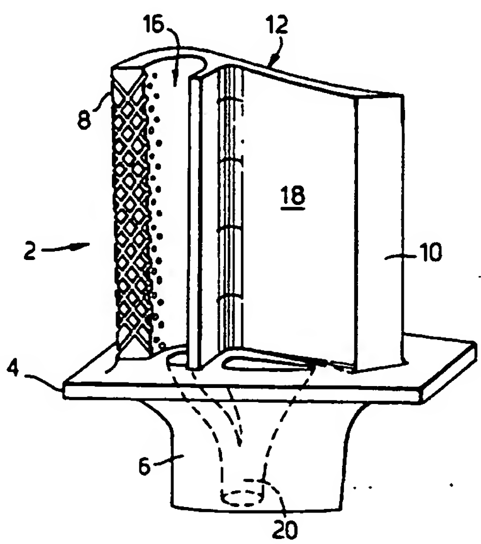
GB 2077363 A	GB 1589191 A	GB 1561103 A
GB 1446045 A	GB 1257041 A	GB 1175816 A
GB 0845227 A	GB 0815596 A	EP 0641917 A1
EP 0375175 A1	US 5370499 A	US 5342172 A

(58) Field of Search
UK CL (Edition O) **F1V VCAA**
INT CL^6 **F01D 5/00 5/12 5/14 5/18 9/00 9/02 9/04 , F04D 29/00 29/26 29/32 29/38 29/40 29/52 29/54 29/58**
ONLINE WPI

(54) **Air cooled wall**

(57) A cooled wall (eg. for a turbine blade leading edge, or a heat sink for an electronic circuit) contains a three-dimensional array of variously angled rectilinear passages or holes which are fed with cooling air. The passages are arranged in interleaved layers, the passages in a layer being parallel but subtend an included angle with respect to the passages in an adjacent layer. The hole pitch and spacing between neighbouring layers preferably being such that each passage in one layer intersects a number of passages in adjacent layers thus forming a multiplicity of labyrinthian cooling passages. The effects of blockages are much-reduced and the total internal convective cooling efficiency is greatly increased. Various patterns of holes and passages are disclosed.

Fig.1.



GB 2 310 896 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig.1.

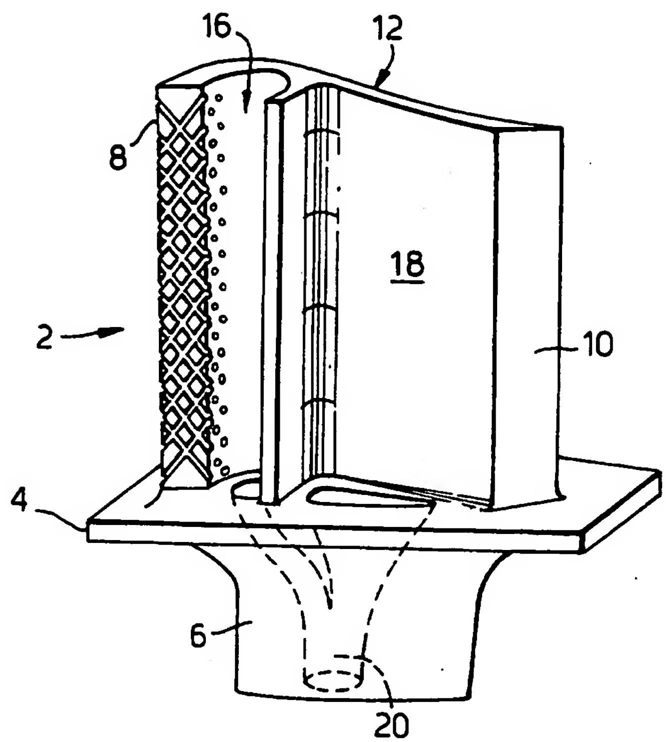


Fig.5a.

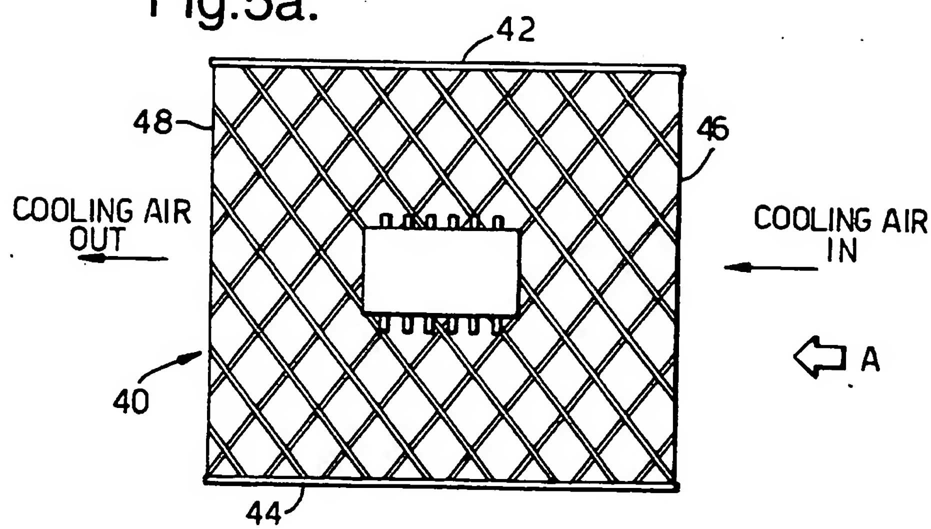


Fig.5b.

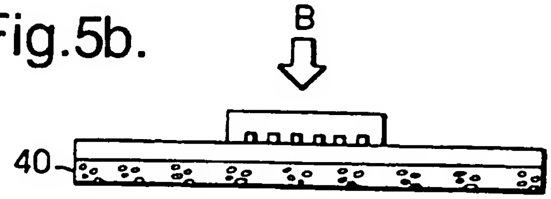


Fig.2.

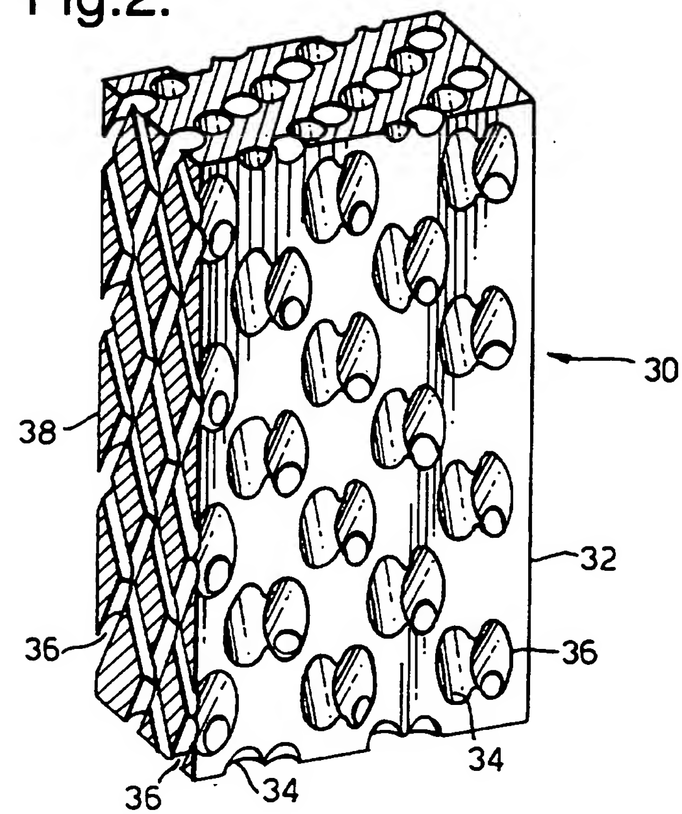

30
38
32
36
36
36
34
34

Fig.3.

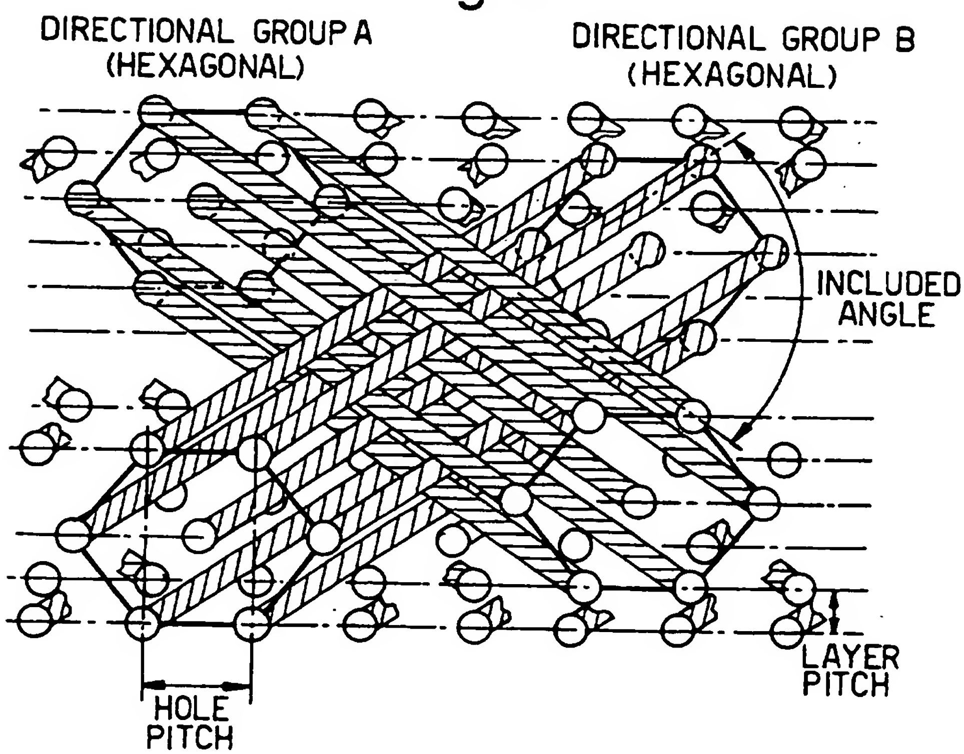
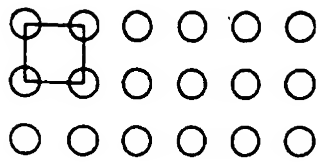
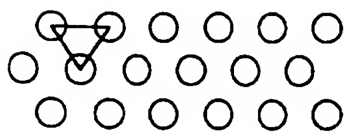

DIRECTIONAL GROUP A
(HEXAGONAL)
DIRECTIONAL GROUP B
(HEXAGONAL)
INCLUDED
ANGLE
LAYER
PITCH
HOLE
PITCH

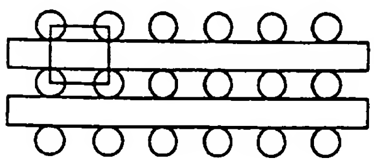
Fig.4.



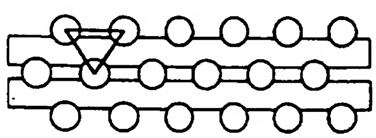
RECTANGULAR FILM (RF)
HOLE PITCH = 2d
LAYER PITCH = 2d



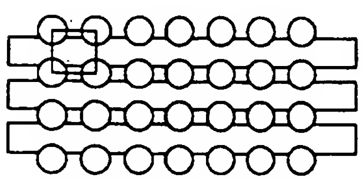
HEXAGONAL FILM (HF)
HOLE PITCH = 2d
LAYER PITCH = 1.73d



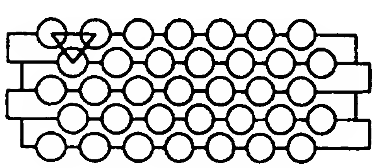
RECTANGULAR MATRIX (RM)
HOLE PITCH = 2d
LAYER PITCH = 1d



HEXAGONAL MATRIX (HM)
HOLE PITCH = 2d
LAYER PITCH = 0.87d
SA = 2.03



RECTANGULAR MATRIX
COMPRESSED (RMC)
HOLE PITCH = 1.5d
LAYER PITCH = 0.75d
SA = 2.35



HEXAGONAL MATRIX
COMPRESSED (HMC)
HOLE PITCH = 1.5d
LAYER PITCH = 0.65d
SA = 2.90

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FLUID COOLED WALL

The invention relates to an fluid cooled wall. In particular, it concerns the arrangement of a matrix of cooling holes in the boundary wall of a hollow aerofoil blade or vane.

It has long been common practice to extract heat from the walls of objects such as aerofoil blades and vanes by passing a cooling fluid, such as air, through holes formed in the walls of the object. This method of cooling has the additional advantage that where the holes extend fully through the walls used cooling air may be arranged to form an effusion cooling film over the hot, external surface. A plurality of factors influence the design of these cooling holes. On one hand there is the diameter, length and spacing of the holes plus the available pressure differential and available cooling flow rate which affect the amount of heat extracted, while on the other hand are restrictions imposed by the economies and discipline of manufacturing.

Inevitably, in a gas turbine engine cooling arrangement a cooling air flow is derived from and driven by a compressor bleed, so any cooling flow represents a loss of engine cycle efficiency. At the same time the heat extraction capacity of the cooling system directly limits the maximum gas stream temperature at turbine entry and thus the power rating of the engine. Consequently an improved heat extraction arrangement for the hottest parts of an engine which also allows higher operating temperatures to be run promises a double improvement.

Expressed in its broadest sense the invention resides in providing a matrix of cooling holes extending through a wall requiring cooling. The term matrix is used here to represent a three-dimensional array of cooling holes

extending through the wall. The cooling holes may have any suitable cross-section.

A three-dimensional array of helical cooling holes in the leading edge of an airfoil blade is known from EP-0641917 A1. In this a multiplicity of helically curved holes extend through the airfoil wall from an interior cavity to discharge cooling fluid over the exterior surface of the airfoil. The curvatures of the holes are chosen with regard to the angle at which coolant is discharged so that upon discharge the coolant will conform to the curvature of the outer surface of the leading edge. Also the cooling effectiveness is improved because the cooling hole surface area, the holes have a rectangular cross-section, is moved closer to the outer surface of the leading edge. The document, furthermore, alleges that the helically curved holes may be cast or drilled in any well known manner, such as by electro-chemical milling, laser drilling or the like. It is certainly not apparent at the present time to one skilled in the art how curved holes may be formed by laser drilling. Moreover, minimum dimension restrictions and manufacturing tolerances inherent in the techniques of core casting and ECM will yield cooling holes of inevitably, and undesirably, large internal dimensions and spacing.

Thus, within the state of the art comprising what is common knowledge and the disclosure of EP-0641917 A1 there remains a potential requirement for improved wall cooling using relatively small-dimensioned, closely packed fluid cooling holes. The present invention is intended to remedy this shortcoming.

According to the present invention there is provided an air cooled object having a boundary wall formed with a multiplicity of cooling passages extending therethrough,

said passages being arranged in a plurality of layers, the passages in alternate layers being formed at opposite angles to a surface of the wall, and the layer pitch being chosen so that passages in adjacent layers intersect.

The present invention, and how it may be carried into practice, will now be described in more detail with reference to the embodiments illustrated in the accompanying drawings, in which:

Figure 1 shows a partly sectioned view of an air cooled gas turbine blade including a matrix cooled leading edge,

Figure 2 shows an enlarged view a volume element of the cooling matrix of Figure 1 illustrating the overlaps and intersections of the matrix arrangement,

Figure 3 illustrates the internal disposition of cooling holes in any hexagonal group cooling hole matrix,

Figure 4 illustrates in schematic form several alternative cooling hole grouping arrangements,

Figure 5a illustrates in plan view a micro-chip mounted on a matrix-cooled base, and

Figure 5b illustrates a side view of the micro-chip and cooled base of Figure 5a.

Referring firstly to Figure 1 there is shown one embodiment of the invention as applied to cooling the leading edge of a turbine blade for a gas turbine aero-engine. Essentially the blade comprises an airfoil section 2, a platform section 4 and a root section 6.

The airfoil section 2 is hollow and is defined by a leading edge 8, a trailing edge 10, a suction surface 12 and a pressure surface which has been omitted from the drawing to show more clearly the internal structure of the airfoil. The closed tip of the airfoil or shroud section has also been omitted from the drawing for clarity.

The hollow interior of the airfoil section is divided by a longitudinal, internal dividing wall 14 into a spanwise extending leading edge passageway 16 and a corresponding trailing edge passageway 18. At the base of the airfoil section apertures in the platform section 4 connect the passageways 16,18 to a further bifurcated passage 20 extending through the root section 6. When assembled onto a disc as part of a rotor stage the root passage 20 is in open communication with a source of cooling fluid. Thus cooling fluid, usually from a compressor bleed, is supplied to the internal cavities 16,18 of each blade.

The cooling fluid may be utilised for blade cooling in various ways, impingement cooling of internal surfaces for example is well known. The present invention is particularly concerned with the cooling arrangements employed in connection with the leading edge 8. Basically a multiplicity of cooling holes, indicated for example at 22, are formed passing through the leading edge to allow the escape of cooling fluid from the spanwise passage 16. This escaping fluid provides a dual cooling action: first, during its passage through the cooling holes 22 it absorbs heat from the surrounding metal of the leading edge region, and second, on being discharged from the holes 22 the fluid conforms to the outer surface of the leading edge 8 and forms a film of coolant covering the leading edge.

The leading edge is normally the hottest region of a blade and the maximum operating temperature of the metal of metal alloy in the body of the leading edge constitutes a limiting factor. The efficiency with which heat can be extracted from the leading edge region 8 therefore has a direct effect on the upper operating limit of the blade and the turbine stage. The invention tackles this problem by providing multiple layers of closely-packed cooling holes 22 in the leading edge region 8. The holes 22 are angled with respect to the spanwise extending external surface of the blade and each has a small diameter to maximise surface area per unit volume. Close-packing is achieved by arranging the holes in a complex matrix.

The matrix of cooling holes is illustrated in more detail in Figures 2 and 3. Figure 2 shows a rectangular volume element 30 from the leading edge region of the airfoil of Figure 1, in which the longest side dimension is taken in the spanwise direction. The largest, visible side face 32 may be the inner surface of the airfoil, or at least part of that surface.

For reasons of pictorial clarity the face 32 is depicted as planar whereas in practice the inner airfoil face would be curved, but to show this would complicate the representation of an already complex matrix of angled, intersecting holes.

Essentially the matrix of cooling holes comprising a three-dimensional matrix of angled, ascending holes 34 which is interleaved with a second three-dimensional matrix of angled, descending holes 36. In both sets the holes are formed in parallel directions with a regular inter-hole pitch and are arranged in parallel layers with a regular layer pitch. Furthermore, the layers of the

two sets of holes are interleaved so that the holes of any two adjacent layers are angled in opposing directions thereby defining between them an included angle. The included angle is indicated in Figure 3 together with "hole pitch" and "layer pitch" dimensions. In Figure 2 the exposed face 38 of the rectangular volume element intersects layers of both ascending holes 34 and descending holes 36 revealing the included angle of that arrangement to be an obtuse angle. It will also be apparent from inspection of the drawings that the holes of adjacent layers intersect indicating in this example that the layer pitch is less than one hole diameter. As a result the layers of intersecting holes form not only two arrays of rectilinear passages but also a labyrinthine network of interconnecting passageways. Consequently cooling air may be exchanged between passages in adjacent layers. The internal surface area per unit volume exposed to cooling flow is substantially increased for greater convective cooling efficiency by a reduced pitch between rows or layers of holes. Heat may be readily exchanged between the flows in intersecting passageways for more even cooling by reducing the effect of the hot spots, and even the effect of blocked individual passageways is substantially reduced. Furthermore the heat transfer between the cooling air and the metal of the blade or vane walls is also enhanced by the flow disrupting action of the intersections.

Figure 4 illustrates several possible matrix arrays each characterised by the essential dimensions of hole pitch and layer pitch for instant comparison. In each case a calculation of the surface area (SA) per unit volume, relative to the rectangular film matrix, is provided.

The rectangular film matrix is schematically illustrated in the uppermost diagram, where the hole pitch and layer

pitch are given as equal to twice hole diameter and the surface area measurement is SA=1. Note that the holes in adjacent layers are not staggered thus giving rise to the annotation rectangular matrix.

The next arrangement titled hexagonal film has the holes staggered in adjacent layers with layer pitch reduced to 1.73 diameter. Although the holes do not intersect the surface area per unit volume is increased by a third because of the increased number of holes accommodated.

The first arrangement in which holes in adjacent layers intersect is the rectangular matrix. The hole pitch is maintained at 2 diameters but the layer pitch is reduced to 1 diameter and the SA index increases to 1.83.

A further increase is apparent in the hexagonal matrix in which the holes are staggered and the layer pitch is reduced to 0.87 diameter. The greater number of holes accommodated further increases the SA figure to 2.03.

In the final two arrangements illustrated the hole pitch is reduced to 1.5 diameter. The rectangular matrix compressed has a layer pitch of 0.75 diameter giving an SA equal to 2.35, and the hexagonal matrix compressed has a layer pitch of 0.65 diameter and an SA of 2.90.

The final drawing containing two illustrations Figures 5a and 5b shows respectively plan and side elevations of an electronic circuit substrate 40 formed with an internal matrix of cooling passages according to the invention. The substrate shown is square in plan and is formed with an internal network of intersecting passages disposed in layers parallel to the upper and lower surfaces. The passages thus emerge along all four side edges of the substrate. The passages along two opposite side edges 42

and 44 are sealed, or alternatively interconnected by some form of hollow capping means, leaving the other two edges 46 and 48 to function as cooling fluid inlet and outlet respectively. These side edges 46,48 could be connected, by means not shown, to manifolds in a cooling fluid circuit.

In all of the above described arrangement to cooling holes or passages may be formed relatively simply by existing manufacturing techniques. For example, the holes may be formed by laser drilling, mechanical drilling or electro-chemical machining in a separate manufacturing step after the basic component has been manufactured. Alternatively, the holes could be formed simultaneously in the basic component manufacturing process, for example during casting. In this technique a silica or alumina core representing the matrix of passages is inserted into a mould prior to casting by a lost wax process for example as is used in the manufacture of internal cooling passages in an airfoil blade. Following solidification and cooling the core is dissolved away by chemical action to leave the hollow passages. Since the invention is suited to the manufacture of a cooling matrix employing small diameter, closely spaced holes it may be preferred to form the holes in a separate step, such as by laser drilling.

As previously mentioned the holes need not be of circular cross-section; and could be square or rectangular, nominally anyway, or any other shape that can be manufactured. Thus, references to hole diameter are to be understood to refer to the hole dimension in the relevant direction.

CLAIMS

1 A fluid cooled object having a boundary wall formed with a multiplicity of cooling passages extending therethrough, said passages being arranged in a plurality of layers spaced apart one layer from another, and the passages in alternate layers are formed at opposite angles to a surface of the wall.

2 A fluid cooled object as claimed in claim 1 wherein the spacing between adjacent layers has a pitch less than two hole diameters.

3 A fluid cooled object as claimed in claim 1 or claim 2 wherein the spacing between adjacent layers has a pitch such that passages in adjacent layers intersect.

4 A fluid cooled object as claimed in any preceding claim wherein the cooling holes are arranged in layers, and the angles of the cooling holes in one layer is different to the angles of the cooling holes in an adjacent layer.

5 A fluid cooled object as claimed in claim 4 wherein the matrix of cooling holes is arranged in layers of alternately angled holes.

6 A fluid cooled object as claimed in any preceding claim wherein the cooling holes are arranged in several discrete directions and holes extending the same direction are arranged in regular patterns.

7 A fluid cooled object as claimed in any preceding claim wherein the boundary wall encloses a region of

pressurised cooling air at a pressure higher than that existing on the opposite side of the wall such that, in use, a pressure differential exists across the wall to produce a flow of cooling air through the matrix of cooling holes.

8 A fluid cooled object as claimed in any preceding claim wherein the object comprises an hollow aerofoil blade or vane and the boundary wall is shaped to form a blade suction surface, a pressure surface, a leading edge and a trailing edge.

9 A fluid cooled object as claimed in any preceding claim wherein the matrix of cooling holes are formed in the leading edge of the blade or vane.

10 A fluid cooled object as claimed in any preceding claim wherein at least some of the leading edge cooling holes are formed at an angle selected to establish a surface cooling film extending from the leading edge of the blade or vane in a downstream direction.

11 A fluid cooled object as claimed in any of claims 1 to 6 wherein the boundary wall comprises a heatsink of the kind used, for example, for mounting an electronic circuit.

12 A method of manufacturing a fluid cooled object as claimed in any preceding claim wherein the step of forming the matrix of cooling holes is integral with the process of manufacturing the object.

13 A method of manufacturing a fluid cooled object as claimed in claim 11 wherein the matrix of cooling holes is cast integrally with the object.

14 A method of manufacturing a fluid cooled object as claimed in any of claims 1 to 10 wherein the matrix of cooling holes is formed in a separate manufacturing step by a process of laser drilling, electro-chemical machining or mechanical drilling.

15 A fluid cooled object as claimed in any preceding claim wherein the cooling fluid comprises air.

16 A fluid cooled object substantially as described with reference to the accompanying drawings.

The Patent Office

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Application No: GB 9604652.9
Claims searched: 1-16

Examiner: C B VOSPER
Date of search: 24 May 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): F1V(VCAA)

Int Cl (Ed.6): F01D 5/00,5/12,5/14,5/18,9/00,9/02,9/04; F04D29/00,29/26,29/32,29/38,29/40,29/52,29/54,29/58

Other: ONLINE WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB2077363A	UNITED (fig.2, noting sinuous passages)	1 at least
X	GB1589191	DIRECTOR(figs.1,2, noting respective layers of passages 37,38)	1,8,9 at least
X	GB1561103	GENERAL (fig.1)	1,2 at least
X	GB1446045	GENERAL (figs. 2,3)	1-5,7,8
X	GB1257041	ROLLS (figs. 1,3)	1,3,4 at least
X	GB1175816	ROLLS (fig.2)	1,3,4 at least
X	GB0845227	ROLLS (figs. 1,3)	1-3 at least
X	GB0815596	CALIFORNIA (fig. 1)	1,2 at least
X	EP0641917A1	UNITED (figs. 5,6)	1,4,8,9 at least
X	EP0375175A1	ROLLS (figs. 3A-6A)	1,3,4 at least
X	US5370499	LEE/GENERAL (fig.4)	1-8 at least

X Document indicating lack of novelty or inventive step	A Document indicating technological background and/or state of the art.
Y Document indicating lack of inventive step if combined with one or more other documents of same category.	P Document published on or after the declared priority date but before the filing date of this invention.
& Member of the same patent family	E Patent document published on or after, but with priority date earlier than, the filing date of this application.

The Patent Office

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Application No: GB 9604652.9
Claims searched: 1-16

Examiner: C B VOSPER
Date of search: 24 May 1996

Category	Identity of document and relevant passage	Relevant to claims
X	US5342172 COUDRAY/SNECMA (figs.1,3)	1,4-9 at least

X Document indicating lack of novelty or inventive step
Y Document indicating lack of inventive step if combined with one or more other documents of same category.
& Member of the same patent family

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P Document published on or after the declared priority date but before the filing date of this invention.
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